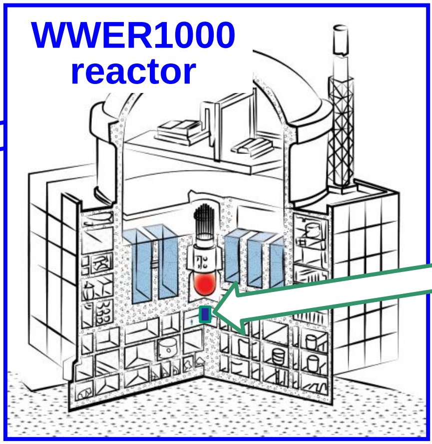
DANSS Reactor Antineutrino Project: Status and First Results

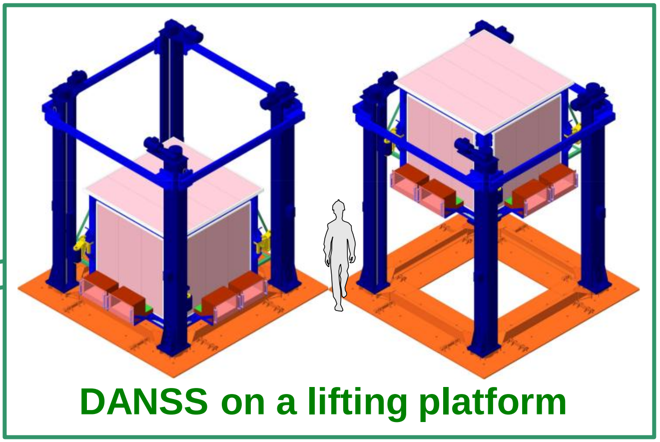
Dmitry Svirida for the DANSS Collaboration ITEP-JINR

WIN 2017

DANSS project

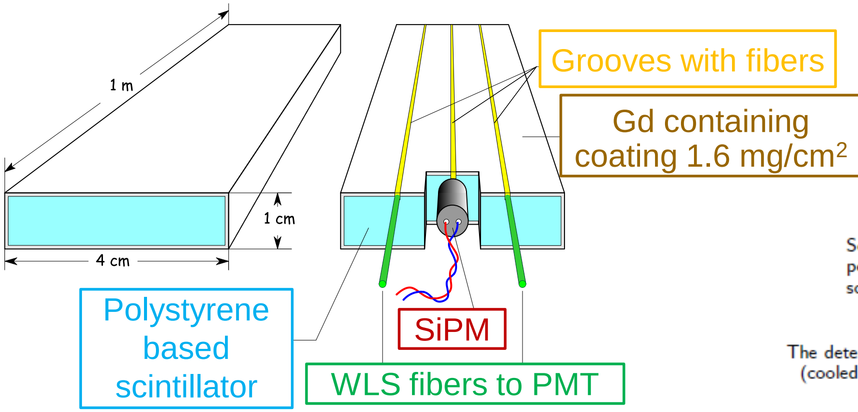
Detector of reactor AntiNeutrino based on Solid Scintillator

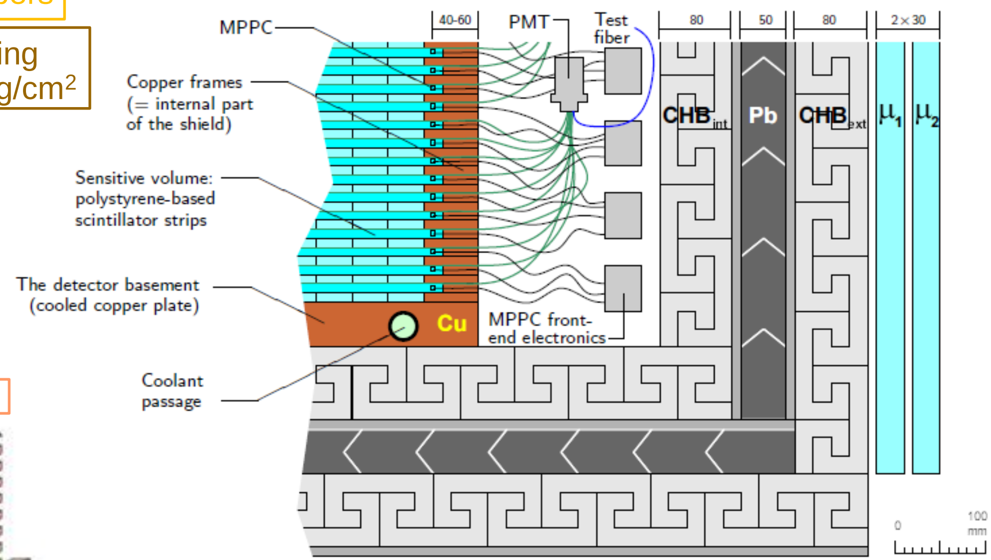


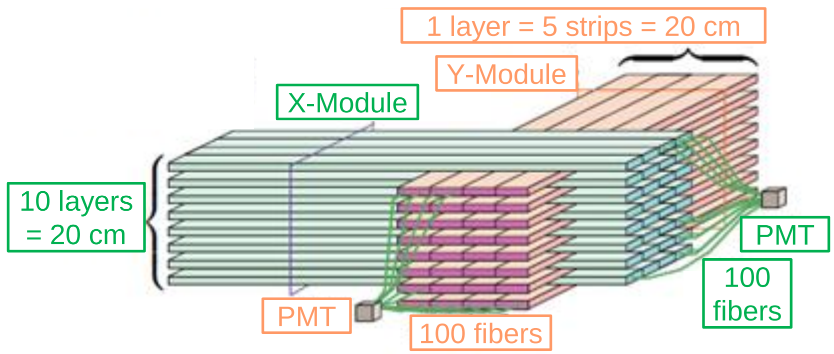


- Detection of the reactor antineutrino spectrum through the reaction of inverse β-decay: $\tilde{\nu}_e + p \rightarrow e^+ + n$
- Designed to contain no flammable or other dangerous liquids or materials
- Located right below the core of 3.1 GW commercial reactor
- Uses reactor body and shielding for cosmic background suppression ~50 m.w.e.
- Lifting system allows to change the distance between the centers of the detector and of the reactor core from 10.7 to 12.7 m
- Sensitive volume 1 m^3
- Physics goal: sterile neutrino search in the short range region

DANSS detector design



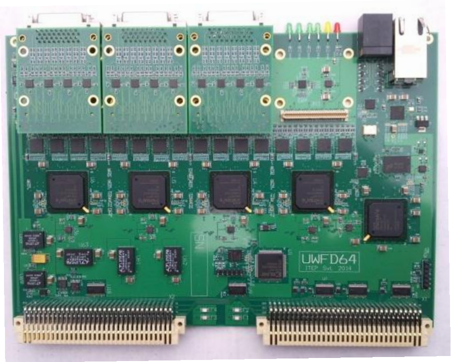




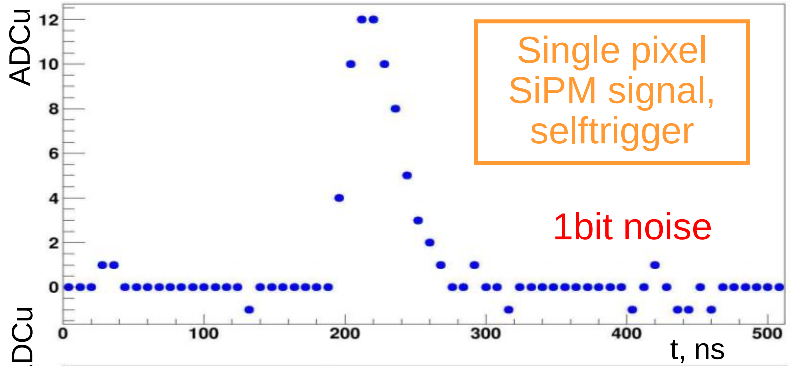
- 2500 scintillator strips with Gd containing coating for neutron capture
- Light collection with 3 WLS fibers
- Central fiber read out with individual SiPM
- Side fibers from 50 strips make a bunch of 100 on a PMT cathode = Module

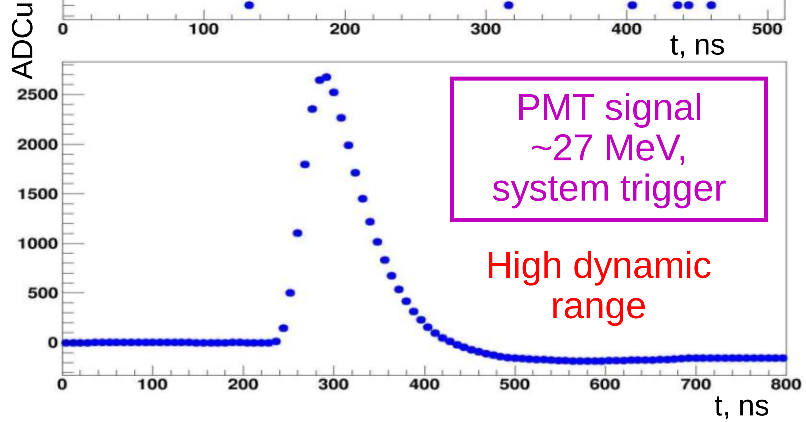
- Two-coordinate detector with fine segmentation – spatial information
- Multilayer closed passive shielding: electrolytic copper frame ~5 cm, borated polyethylene 8 cm, lead 5 cm, borated polyethylene 8 cm
- 2-layer active μ-veto on 5 sides

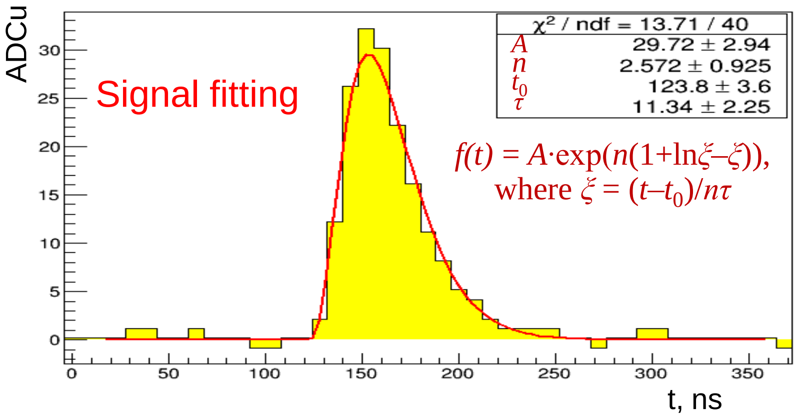
Data acquisition system



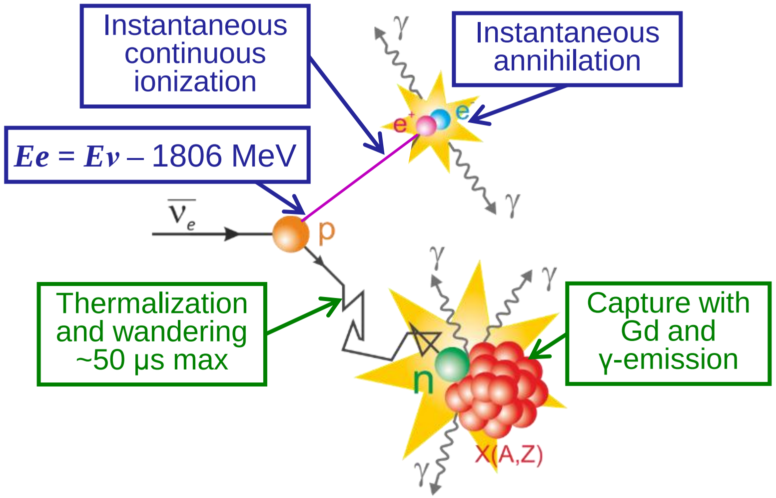
- Preamplifiers PA in groups of 15 and SiPM power supplies HVDAC for each group inside shielding, current and temperature sensing
- STP cables to get through the shielding
- Total 46 Waveform Digitisers WFD in 4 VME crates on the platform
- WFD: 64 channels, 125 MHz, 12 bit dynamic range, signal sum and trigger generation and distribution (no additional hardware)
- 2 dedicated WFDs for PMTs and μ-veto for trigger production
- Each channel low threshold selftrigger on SiPM noise with decimation
- Exceptionally low analog noise ~1/12 p.e.

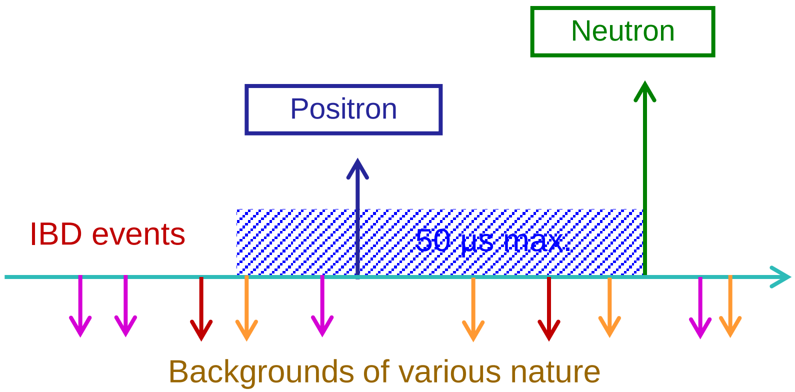






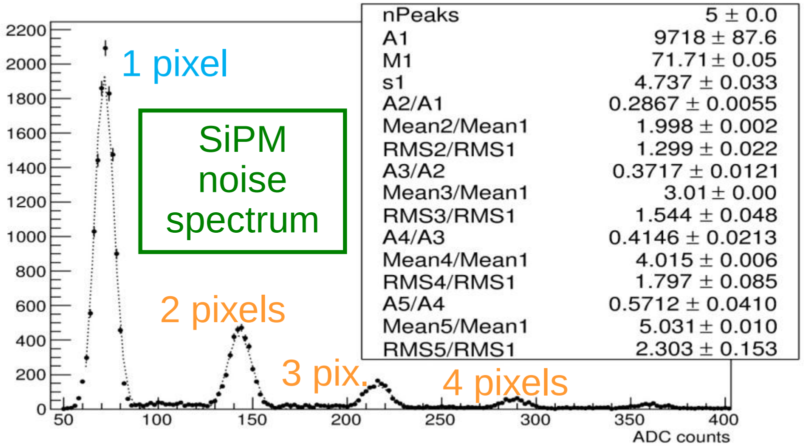
IBD basics and triggering



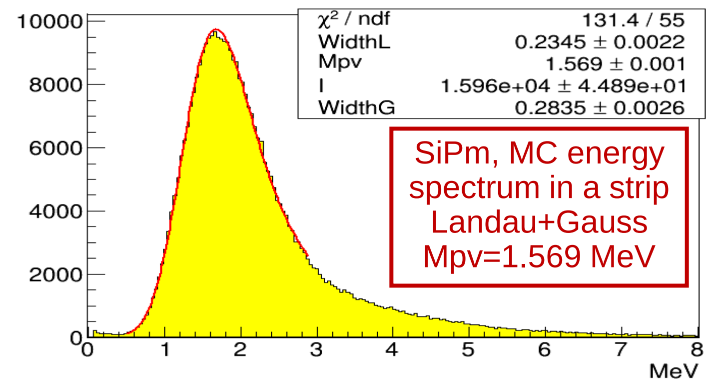


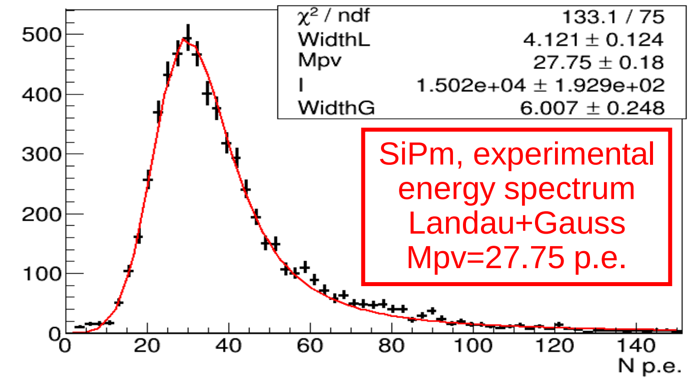
- Positron: instantaneous response from ionization and annihilation
- Neutron: thermalization (~5 μs) and up to ~50 μs travel before Gd capture with γ-emission
- Not practical to store 50 μs records
- Separate recording of positron and neutron candidates, **time correlation OFF-Line**
- System trigger: <Energy deposit in the sensitive volume >0.6 MeV> OR <VETO>
- Trigger rate ~1 kHz, dead time 600 ns, negligible data loss, soft trigger condition
- All PMTs and SiPMs are recorded with zero suppression threshold ~0.5 p.e.
- Good opportunity for accidental background estimates and muon-correlated analysis

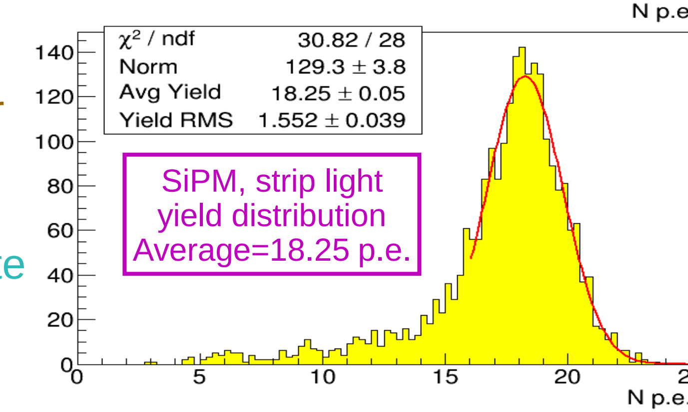
Energy calibration



- Noise spectrum: SiPM calibration in terms of ADCu/p.e., including cross-talk accounting
- Temperature dependent – after every instability
- Strip light yield, p.e./MeV – stable, ~twice per month
- Using vertical muons: PMT tower 100x20x20 cm
- Compare MC-simulated energy deposit to the experimental by Mpv
- Direct muon calibration for PMTs: ADCu/MeV, similar Mpv technique
- SiPMs: ~18 p.e./MeV, PMTs ~20 p.e./MeV
- Attenuation ~20%/m, corrected by second coordinate
- Energy resolution is dominated by p.e. statistics – add SiPM and PMT signals to improve



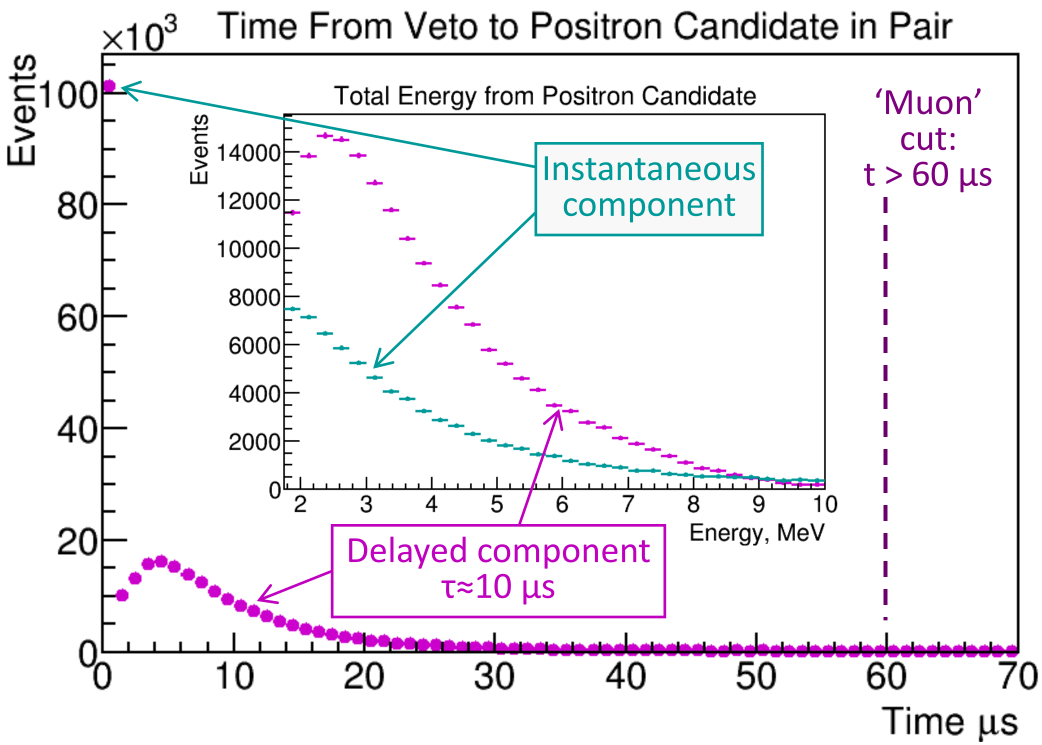




Event building and muon cuts

Building Pairs

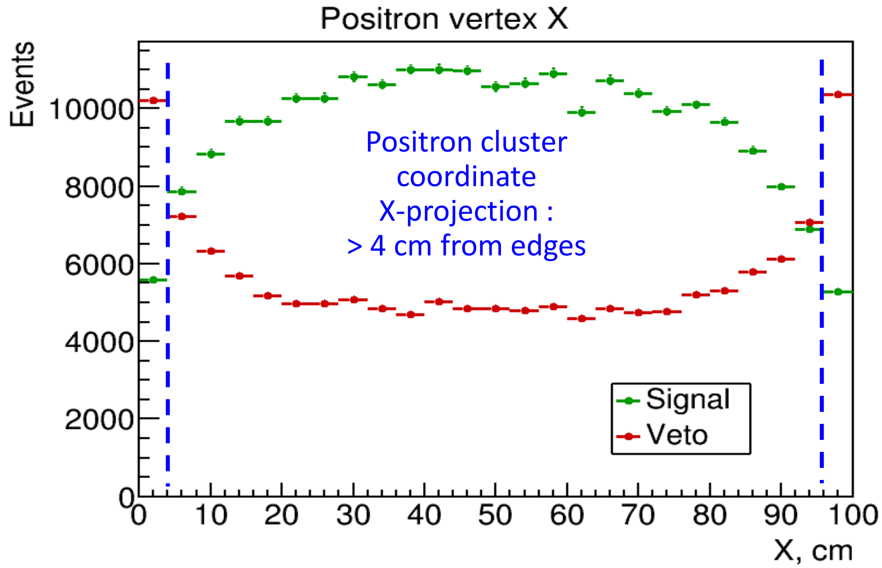
- Positron candidate: 1-20 MeV in continuous ionization cluster
- Neutron candidate: 3-15 MeV total energy (PMT+SiPM), SiPM multiplicity >3
- Search positron 50 μs backwards from neutron

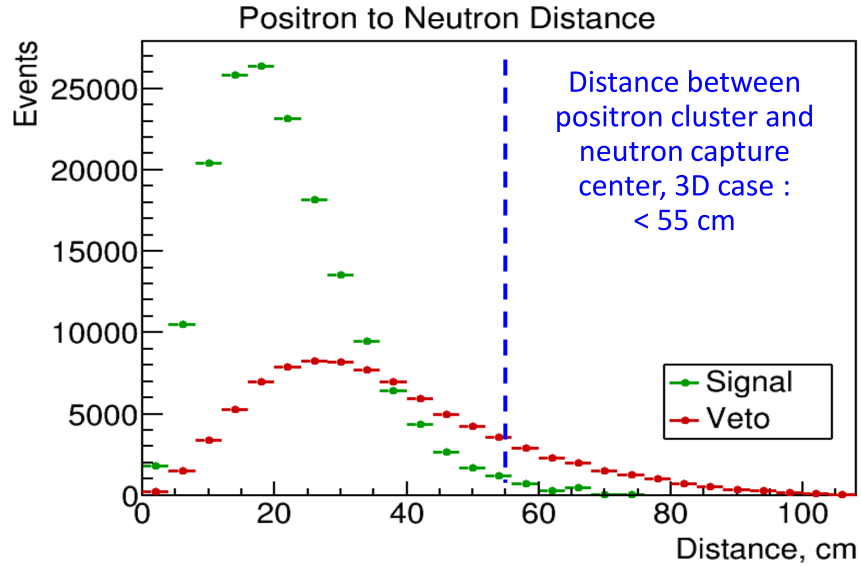


Muon Cuts

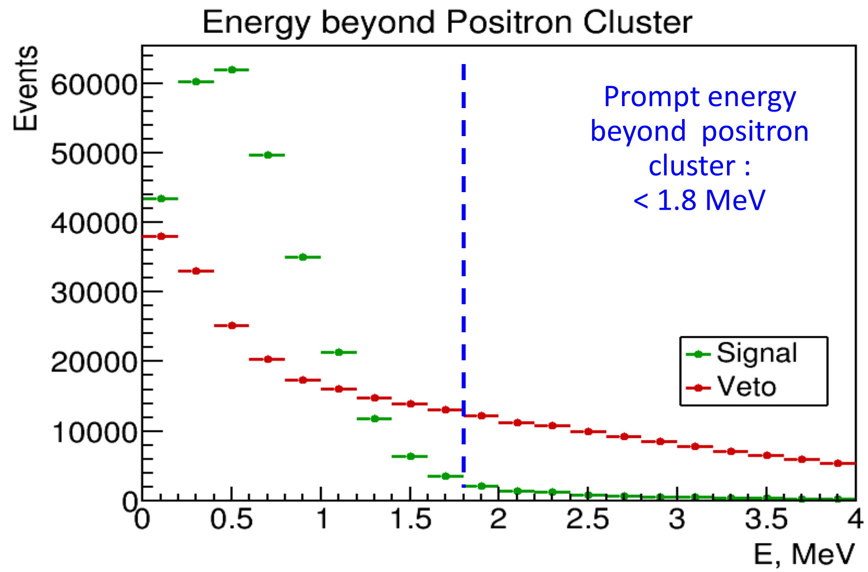
- VETO 'OR':
  - 2 hits in veto counters
  - veto energy >4MeV
  - energy in strips >20 MeV
- Two distinct components of muon induced paired events with different spectra:
  - 'Instantaneous' – fast neutron
  - 'Delayed' – two neutrons from excited nucleus
- 'Muon' cut : NO VETO 60 μs before positron
- 'Isolation' cut : NO any triggers 45 μs before and 80 μs after positron (except neutron)
- 'Showering' cut : NO VETO with energy in strips >300 MeV 200 μs before positron

Additional cuts using fine segmentation

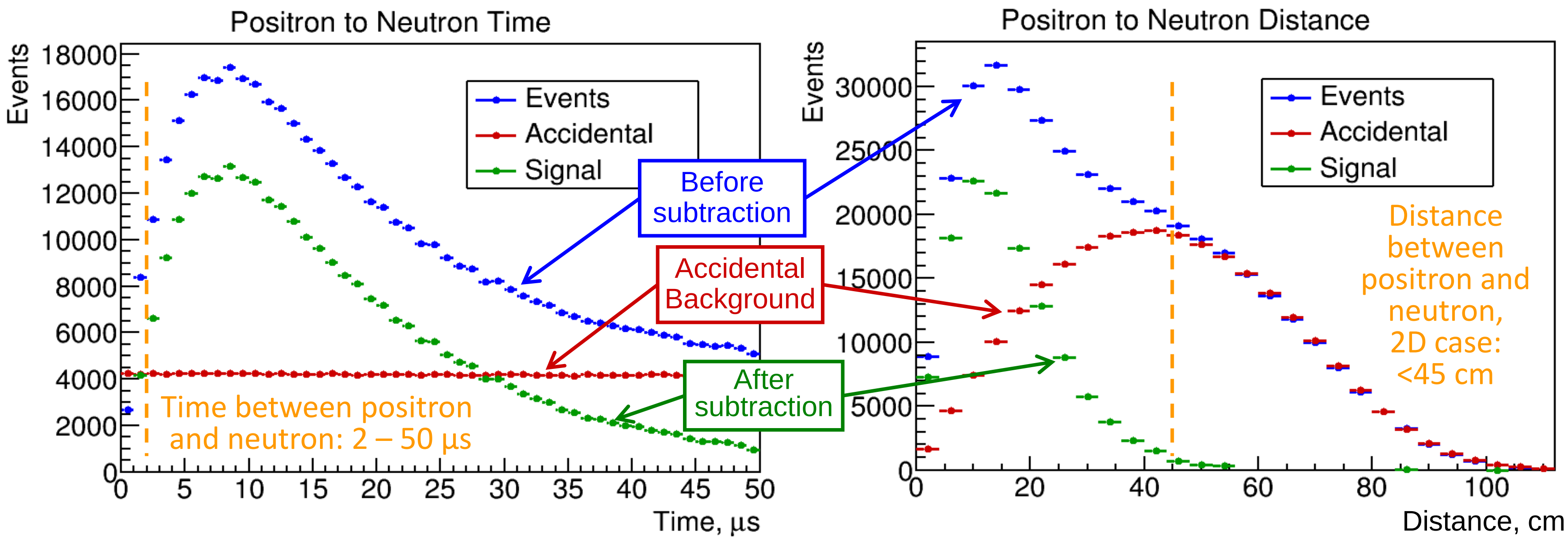




- Comparison of the distributions for the events which passed the muon cut with similar for those accompanied by muons
- Positron cluster position: 4 cm from all edges
- Vertical projection of the distance: <40 cm
- Multiplicity beyond positron cluster: <11
- Totally 8 cuts of this kind
- Reject cosmic background >3 times, but only 15% of the events

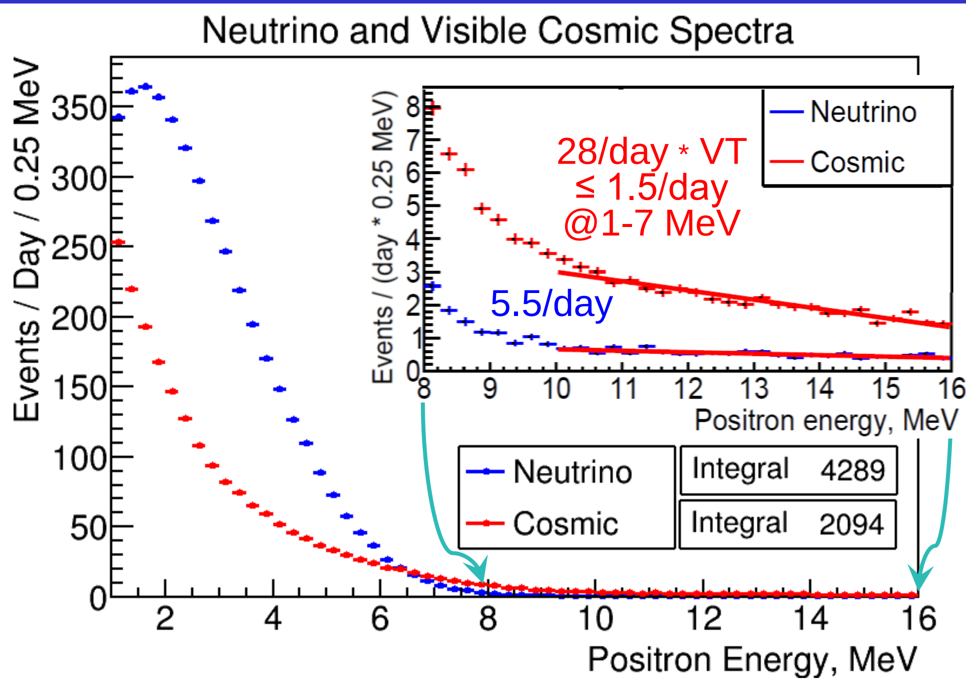


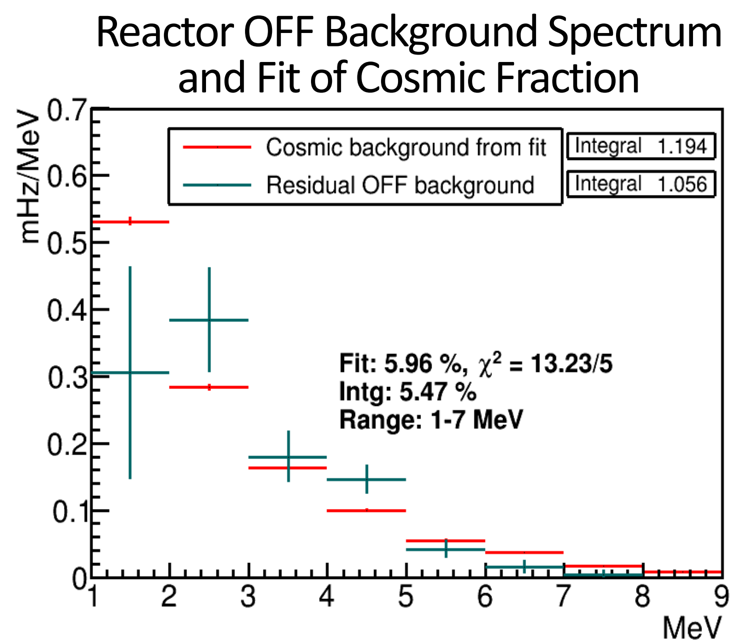
Accidental coincidence background



- Fake one of the IBD products by uncorrelated triggers
- Background events from data: search for a positron candidate where it can not be present – 50 μs intervals far away from neutron candidate (5, 10, 15 etc millisec)
- Enlarge statistics for accidentals by searches in numerous non-overlapping intervals
- Accidentals rate is smaller but comparable to that of the IBD events
- Mathematically strict procedure, does not increase statistical error
- Cuts for the accidental coincidence exactly the same as for physics events
- Any distribution – for physics events, background events and their difference
- Optimization of cuts to reduce accidental contribution => smaller statistical error

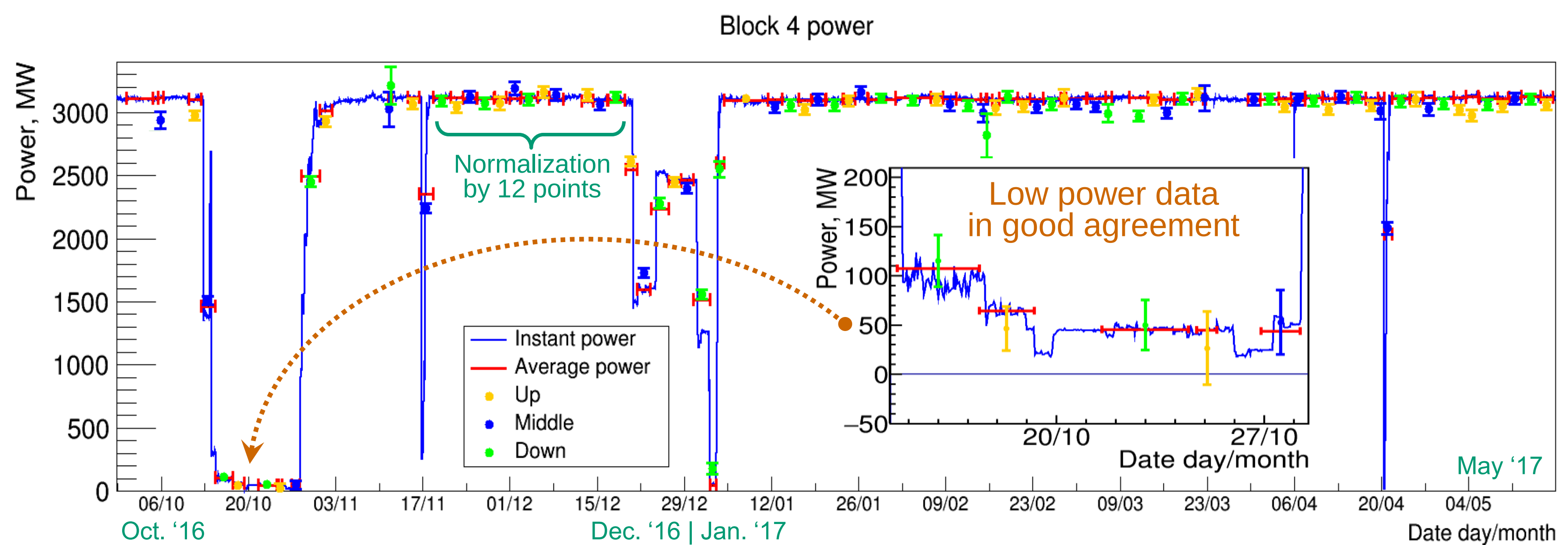
Residual background subtraction



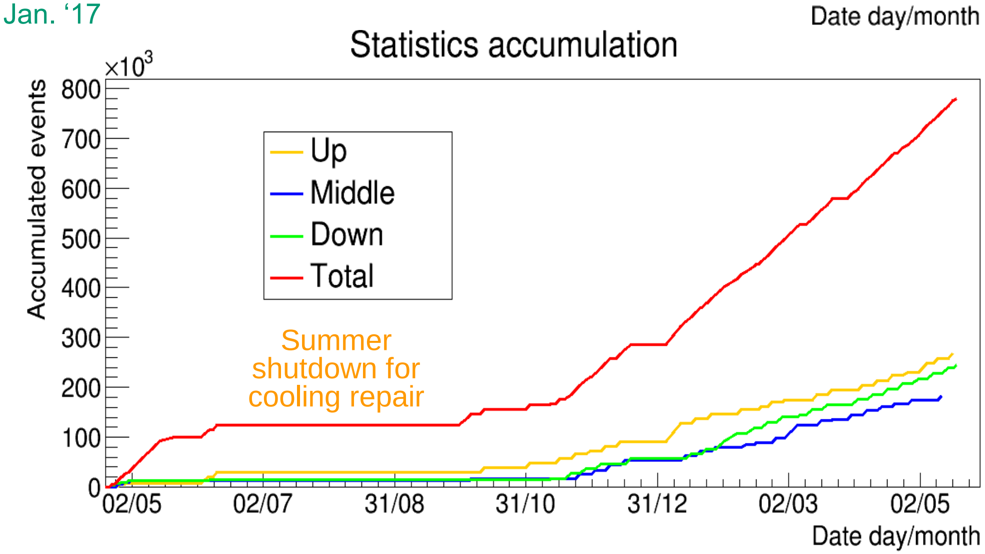


- Fast neutron tails: linearly extrapolate from high energy region and subtract separately from positron and visible cosmic spectra
- Subtract fraction of visible cosmics based on VETO transparency
- Amount of visible cosmics ~50% of neutrino signal
- VETO transparency uncertainty:
    - 2.5% from muon count in sensitive volume, missed by veto -- underestimate
    - 5.5% from ‘reactor OFF’ spectra – poor statistics
- Cosmic background fraction ≤3% of neutrino signal, subtracted
- ^{9}Li and ^{8}He background estimates: < 2.7/day @90% CL

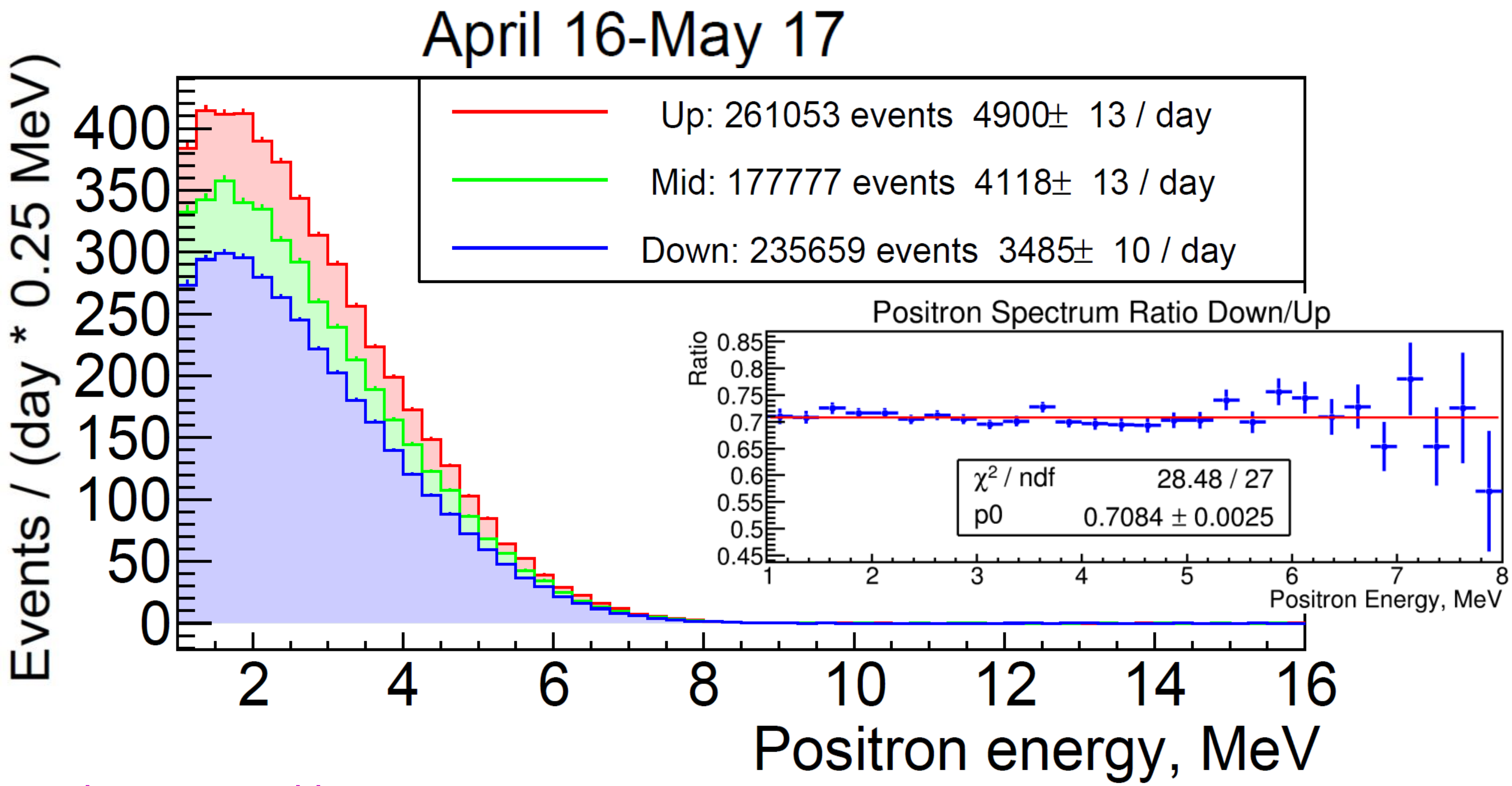
Detector performance



- On power graph:
  - Points at different positions equalized by $1/r^2$
  - Normalization by 12 points in November-December
  - Adjacent reactor flux subtracted (0.45% of full power)
- Statistics @100% power, ~170 days:
  - $7.8 \cdot 10^5$ total
  - $7.0 \cdot 10^5$ in definite positions
  - $6.75 \cdot 10^5$ after QA



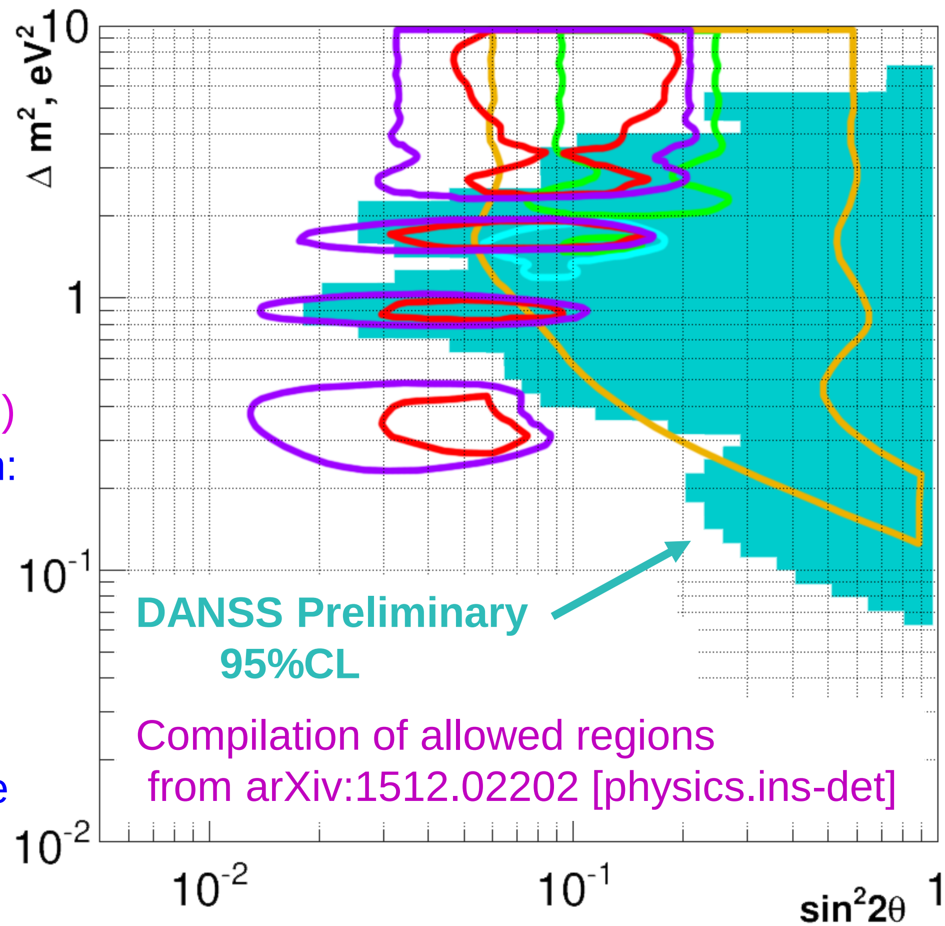
Positron spectrum



- 3 detector positions
- Pure positron kinetic energy (annihilation photons not included)
- About 5000 neutrino events/day in detector fiducial volume of 78% ('Up' position closest to the reactor)
- Down/Up spectrum ratio does not contradict to straight line with current statistics

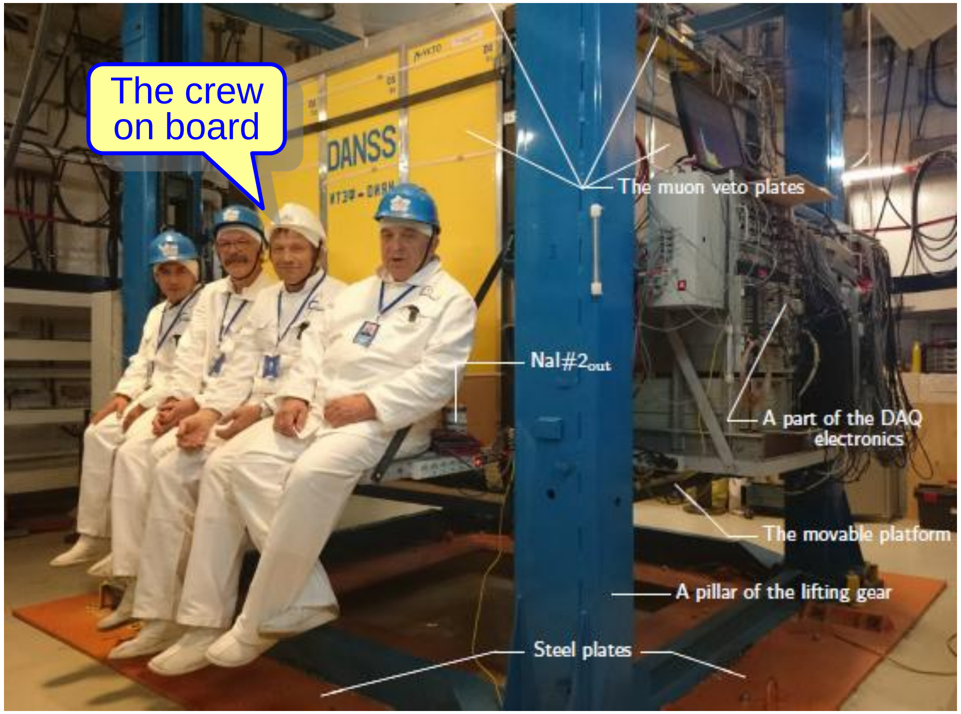
Exclusion region with current statistics

- Based only on Up/Down spectrum ratio -- independent on detector efficiency
- Theoretical curves for each Δm^2 and $\sin^2(2\theta)$ calculated based on:
    - Model neutrino spectrum from Huber and Mueller
    - Fuel burning profile from NPP
    - Detector size
    - Detector energy resolution
- Gaussian CLs method (arXiv:1407.5052)
- Systematics studies include variations in:
    - Reactor burning profile (small)
    - Detector energy resolution
    - Levels of cosmic backgrounds (veto and fast neutrons)
    - Energy intervals used in fit
    - Various combinations of the above
- Most conservative variant is used
- A large fraction of allowed parameter space is reliably excluded by preliminary DANSS results



Summary

- DANSS recorded first data in April 2016 and now takes statistics at full speed of about 5000 antineutrino events per day in the closest position, plan to double statistics by the end of the year
- Expect 8 weeks of planned reactor shutdown in coming July for even better background estimates
- Improve MC for perfect reflection of detector energy response
- Refine detector calibration
- Continue systematic studies
- Elaborate more analysis methods for better sensitivity



The work is partially supported by the State Corporation «RosAtom» through the state contracts H.4x.44.90.13.1119 and H.4x.44.9Б.16.1006 and by Russian Science Foundation, grant 17-12-01145

Thank you !